Drying sage (*Salvia officinalis* L.) in passive solar dryers

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Abstract

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Sage plants (*Salvia officinalis* L.) were dried in the passive dryers in different times of the year. Different passive solar dryers were used to achieve the socio-economical benefits from drying the medicinal plants growing in Sinai area. Drying sage plants might be a source to increase the Bedouin income instead of cannabis or marijuana, especially if it is exported abroad. Four drying methods were used in this investigation to dry sage in two seasons, namely August 2009 and March 2010 before flowering stage. Plants were dried in an Unglazed transpired passive solar dryer with 100% exposure to direct sun-rays, in a greenhouse dryer covered with shading cloth with 50% exposure to direct sun-rays, and with 0% sun-rays while the medicinal plants were protected from sun i.e. in shaded barn. Investigations were carried out under the environmental weather conditions of Ismailia, Egypt. The study revealed that sage can be dried at different times of the year even before the flowering stage of the plants.

Keywords: sage; passive solar dryers; temperature; relative humidity; drying rate; constant

Sage (*Salvia officinalis* L.) is an evergreen plant, lives long, and grows fast. The herb has simple leaves with strong aromatic smell. Sage plants have trichomes. This type of texture attracts dust, which leads to reduction of the herb medicinal quality and the international price, especially if it is dried in the open environment. Sage leaves have gray or gray-green colour, the plant is 60 cm high on average. The plant grows fast in the light yellow soils, especially in Sinai area. The medicinal and aromatic plants have a great importance for both the pharmaceutical industry and the traditional medicine in the Southern Mediterranean countries.

Sage is usually used for medicine for several aims such as carminative, diuretic, antiheroic, analgesic, expectorant, disinfectant, gargle etc. Sage has no side effects in recommended doses. Usage of sage may be in form of tablets or as droplets, tea, and volatile oil. Moreover, it is used in cosmetics for perfumes. Sage has a widespread usage area and it is also used for dyeing of wool carpet and rug yarns (Ölmez, Kayabaşı 2002). Sage has a very old reputation to calm nervousness and cure digestive troubles (Kouhila et al. 2001). Sage has a great industrial significance; many Mediterranean countries where it grows have substantial gains from the production and export of sage (Amr, Dordevic 2000). In their preliminary study on the convection solar drying for aromatic and medicinal plants in solar dryers, Kouhila et al. (2001) presented the relationship between relative humidity and equilibrium moisture content of stage. Lemos et al. (2008) evaluated the influence of the drying air temperature on the essential oil content from medicinal plant (*Melaleuca alternifolia*) dried in fixed-bed dyer with air velocity of 0.51 ± 0.03 m/s and 65% input air relative humidity and drying occurred at 40, 50, 60, 70, and 80°C (three replicates of each). The essential oil was extracted by steam distillation. They found that no statistical differences between the drying treatments. However, when the fresh plants were

Table 1. Relationship between volatile oil yield (% v/w) of sage and drying temperature (Tetenyi 1990)

Drying temperature (°C)	40	50	60	70	80	90	100
(% v/w)	2	1.7	1	0.5	0.5	0.4	0.3

used, reduction in oil content was observed compared to the dried samples in different treatments.

Venskutonis (1997) found that changes in concentrations of sage volatile oils were dependent on the method and drying temperatures.

For temperatures ranging from 40–100°C, the investigations were carried out for volatile oil content in sage for 24 h. It was concluded that higher the drying temperature, the lower volatile oil content was, resulting in lower quality (Table 1).

Growing-sage in Egypt has flowering a stage two times at the first year and three times in the second year; plants begin their flowering stage at the end of March and the flowers are small. The valuable cultivation was obtained within summer time (June, July, and August) as the oil quantity and leaves quality were high (Degawy 1996).

Cannabis, Marijuana (Bango), and opium poppy are cultivated in Sinai area and there is still potential for expansion. Poverty, low economic growth, lack of income alternatives and high unemployment rates combined with a lack of awareness have provided the perfect breeding ground for the illicit crop cultivation in Sinai area. Most of the Bedouins living in the Sinai Peninsula earn their living from limited and subsistence agriculture and animal husbandry, and only few of them from other economic industries (oil, mining, and tourist). To relocate those small industries, medicinal, and ornamental plants plays the key of resolving the problem. Sage is one of the plants which can create broad market and it is a well growing plant in Sinai area.

In this study sage was dried with different passive solar drying methods. No demand for electricity to power the dryer fan helps to improve sage trading in the international market and to be competitive with the world prices and may attract Bedouin of north Sinai to relocate drug cultivation. Using this system does not require additional power resources except solar energy (which is abundant all the year around); at the same time it protects the dried material from stains and dust with keeping the medicinal components.

This study aims to study sage drying at different times of the year using different passive solar drying systems, and to investigate the effect of such drying period on sage drying.

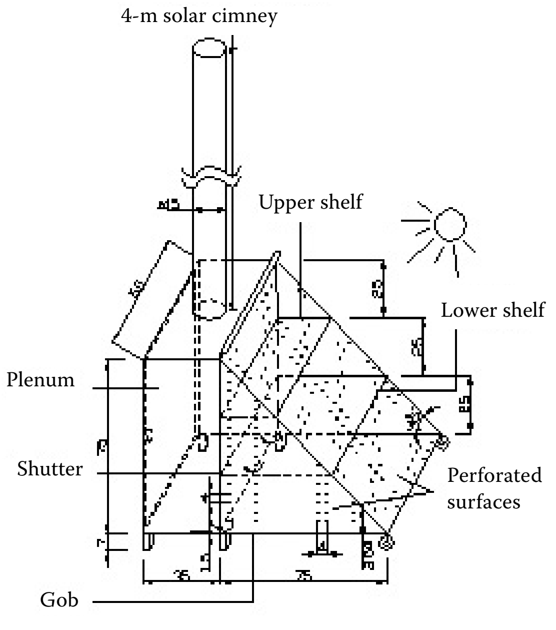

Fig. 1. Unglazed perforated passive solar dryer used for sage drying in summer

MATERIALS AND METHODS

Investigations were carried out at the Department of Agriculture Engineering, Suez-Canal University, Ismailia, Egypt to study the passive solar drying of sage (*Salvia officinalis* L.) at different times of the year, using different passive drying methods. Unglazed passive transpired (perforated) solar dryer (UPPSD) was used in this study for sage drying. Also, in order to investigate the effect of sun-rays on sage drying, plants were exposed to three different amounts of solar radiation: 100% from the total direct sun-rays, 50% from the incident sun-rays in the greenhouse drying covered with 50% shading cloth, and 0% sun-rays in shaded drying barn dryer. Sage was dried in summer (August) as well as in March before flowering stage, with the maximum of volatile oil (Degawy 1996).

Drying methods performed in this investigation on sage were:

Unglazed perforated solar dryer: Fig. 1 illustrates the used unglazed perforated passive solar dryer

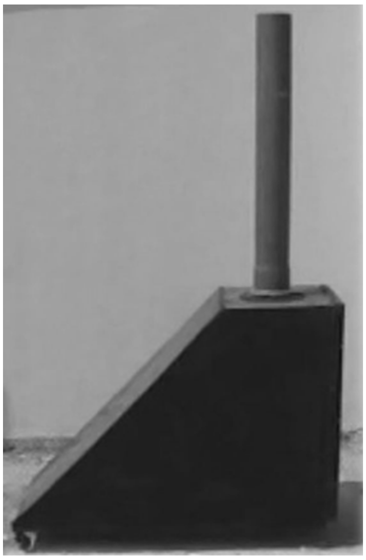

Fig. 2. Plate for the unglazed perforated passive solar dryer with 1-m chimney height used for sage drying in March

Fig. 3. Plate for the greenhouse dryer; beside piece of the shading cloth

with dimensions which was investigated from August, 2009. The upper and lower shelves besides the dryer basement were all used to dry sage. The UPPSD was given previously in details by the author in terms of dimensions and materials. Solar chimney was used instead of the electric air blower (compared to active dryers). Black PVC chimney of 3 mm wall thickness, 127 mm in diameter and 4 m height from the top of the dryer was mounted (4.75 m from the ground base) for summer investigation (August). Meanwhile, when the dryer was used in March fast wind confronted installing as high chimney as in summer time; thus, chimney was shortened to 1 m height, as it is seen in Fig. 2. Also, a transparent acrylic 4 mm thick, 15 cm wide, and 40 cm high was fitted and it was sealed on the back dryer door, it was used as a hatch for visualizing and follow-up the drying process. No barrier or gates (plenum) was used for the dryer. It should be noted that the dryer basement was used in the drying processes to enlarge the dryer capacity in the August study. It was not used in March as it was not helpful for the moisture reduction.

Greenhouse dryer: Uneven-span greenhouse covered by black colour shading cloth was used to dry sage in this study. UV protected polyethylene, which gives the fabric strength and durability, was used as shading cloth. It let 50.8% (counted as 50% shade) rays penetrate the cover to the interior greenhouse environment. The dryer has total area of 12 m^2 (4 m long × 3 m wide), oriented east-west with a door located in the eastern side. The metal structure (foundations) of this dryer was from galvanized steel of 25.4 mm diameter. This dryer was used before as greenhouse. This enable multiuse for recycling the capital cost (i.e. sage production and drying all the year around). The dryer northern side was 2 m high

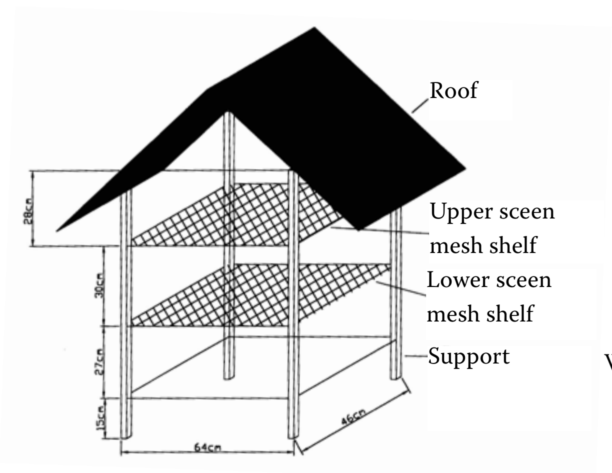

Fig. 4. Shade dryer bar

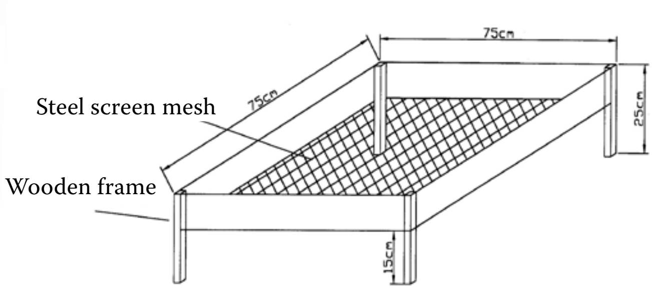

Fig. 5. Drying in tray under the direct sun-rays

while the southern side only 1.1 m. This created two angles of 47.5° with the south and 30° the north sides. The greenhouse dryer is shown in Fig. 3.

Shade drying: Sage was dried under shade barn shown in Fig. 4 under conditions of ambient air temperatures; it was completely protected from the direct sun-rays during the drying processes.

Drying in trays under the direct sun-rays: Sage was also dried under direct sun-rays in the trays shown in Fig. 5.

Dried materials

One of the study targets is to achieve marketable dried sage to be compatible in the medicinal plants market. Leaves of sage plants have bur or fibre (Trichomes texture); it attracts stains and fine dust, especially if it is dried under open environmental conditions in direct sun-rays. Dried sage plants involved in the study had average length of 48 ± 0.08 cm, it was harvested on the morning of the first drying day. The plants were dried either in the dryer or in the shade (in the ambient air) for the trial of the beginning of August, while it was cut down into small pieces of 7.6 ± 1.7 cm long with average 3.5 mm diameter for March one. Sage plants were distributed in different dryers with drying beds (depth) of 5 to 7 cm. Meanwhile iron-mesh boxes of 14 × 7 × 5 cm dimensions each (length, width, and height) were used as enclosure for drying samples. It was spread in all the dryers and it was collected to determine the reduction in mass due to drying at two-hours interval. No chemical additives or treatments were used on fresh plants. Also, the fresh plants were not washed before investigation to keep their microbial load.

Measurements

Measurement campaigns began daily after two hours of the sun-shine with two-hour interval for the following measurements:

Incident radiation was determined for different sides of the drying system in the investigation, i.e. horizontal and vertical sides of (east, west, and north) or sloped sides. Transmitted (penetrated) sun-rays from shade cloth were measured as percentage of the penetrated rays (W/m^2) to that measured outside the shading cloth. It was found as 50.8% from the total incident solar radiation.

Relative humidity (RH) was determined for the ambient air (outside the dryer) and the drying air, these values were used to obtained sage equilibrium moisture content. Using digital psychrometric chart, RH was determined from the measured dry and wet bulb temperatures (psychrometer).

Temperatures for the dryer surfaces, ambient and drying air, ground and surrounding objects were determined in this study using the Ama-Digit-system (Germany)(range from –10 to 110°C, and accuracy of 0.1°C) which was calibrated before using and the S.D. between its readings was of ± 0.25°C.

Wind speed and chimney air velocity: average wind speed as well as chimney air velocity within two-hour interval from the sunrise to the sunset was determined; 60 readings were taken and varied. Wind speed and the chimney air velocity were measured using TESTO 405-V1 Hotwire Anemometer (TESTO, Inc., Sparta, N J, USA) with accuracy of 0.01 m/s.

Moisture contents determination: to determine the samples initial moisture contents, Ohaus® (Ohaus Corp., Florham Park, N J, USA) electric balance was used to weigh the fresh samples and samples after 24 h. The fresh samples were put in an electric oven at 60°C for 24 h. The initial wet basis (w.b.) moisture content (M_i, %) was determined using the following equation:

$$M_i(\text{w.b.}, \%) = \frac{(m_i - m_f)}{m_i} \times 100$$

where:

m_i – initial mass of the dried samples

m_f – final mass of the dried samples

Samples boxes were weight at two-hour interval to determine the average moisture contents for different drying systems.

To determine **sage drying constant (*k*)**, Fig. 6 of Kouhila et al. (2001) was used. Form the given Fig. 6, the moisture removal (*MR*) is a function in the relative humidity (RH):

$$MR = f(\text{RH})$$

The equilibrium moisture content was determined on dry basis (d.b.) for two-hour interval as:

$$M(\text{d.b.}, \%) = \frac{m_i - m_f}{m_f} \times 100$$

Then substituting the equilibrium moisture content (M_e) on dry basis (decimal) to determine (*MR*) according to the following polynomial function:

$$MR = \frac{M_t - M_e}{M_i - M_e} = e^{-kt}$$

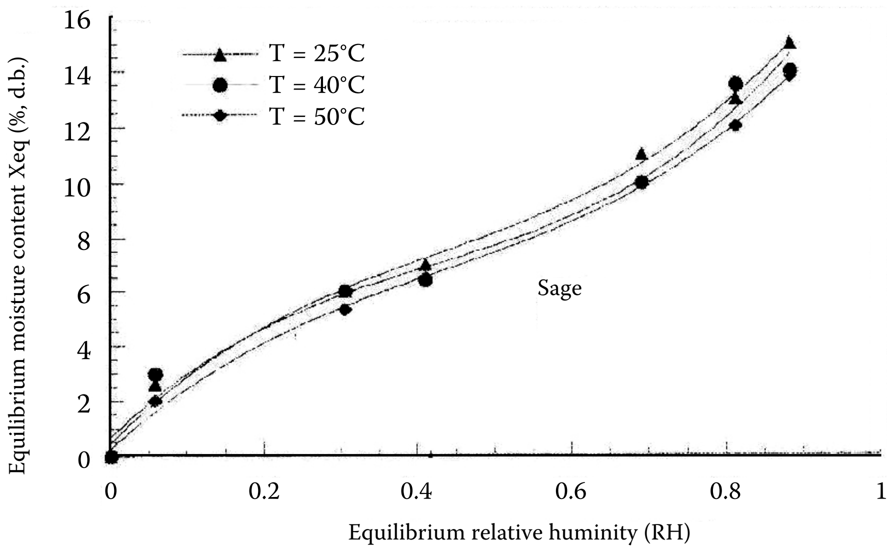

Fig. 6. Equilibrium moisture content for sage versus relative humidity based on experimental results obtained by Kouhila et al. (2001)

Drying constant was determined according to the following relationship:

$$k = -\ln(MR)/t$$

where:

MR – the moisture removal
M_t – moisture content at time t
M_e – equilibrium moisture content
M_i – initial moisture content (d.b.)
t – drying time (s)

Microbiological load analysis for spice and medicinal plant samples was carried out according to the Official Microbiological Methods of WHO (World Health Organization 2005). The samples were prepared as many decimal dilutions as necessary depending on the expected bacterial load of the material being examined. After dilutions prepared, appropriate media were inoculated and incubated at specific temperature.

Mycological studies: for fungi isolation, ten grams of each sample were added to 90 ml portion of sterile saline solution (0.85%) in 500 ml Erlenmeyer flask and homogenized thoroughly on an electric shaker at constant speed for 15 min. Ten fold serial dilutions were then prepared (Aziz, Youssef 1991). One ml portion of suitable dilutions were used to inoculate Petri dishes containing 15 ml dextrose agar fortified by 0.5 mg chloramphenicol/ml medium. Plates were incubated at 28°C for 7–15 days and examined for the growth of moulds. Fungi were isolated and identified according to Raper and Fennel (1977), Domsch et al. (1981), Pitt (1985). For bacteria isolation, nutrient Agar media was applied.

Microbial load was determined as total count for both of bacteria and fungi at the Department of Botany, Faculty of Agriculture, Suez-Canal University, Ismailia, Egypt for the March investigations; it was because of the sandy storm dusts bellowing in this season. Storm brings spores to the dried materials.

RESULTS AND DISCUSSION

Weather conditions throughout the investigations

Table 2 represents average measured weather conditions within the drying process i.e. from the 2nd till the 6th of August, 2009 and from the 8th till 12th of March,

Table 2. Weather conditions throughout the drying of sage

Drying season	G (W/m^2)	Ambient air temperatures (°C)	Relative humidity (%)	Wind speed (m/s)
August	602	31.5	47.5	0.26
March	597	26.2	42.1	0.72

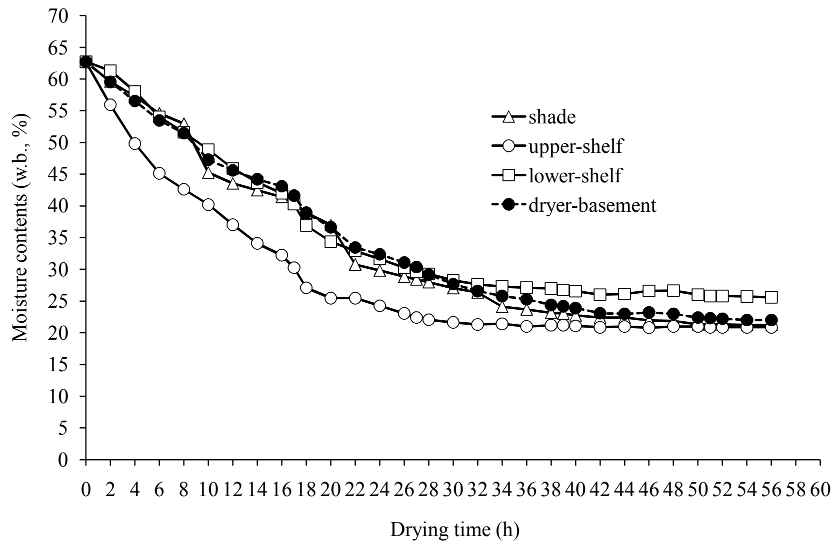

Fig. 7. Moisture content versus drying time for drying sage in summer

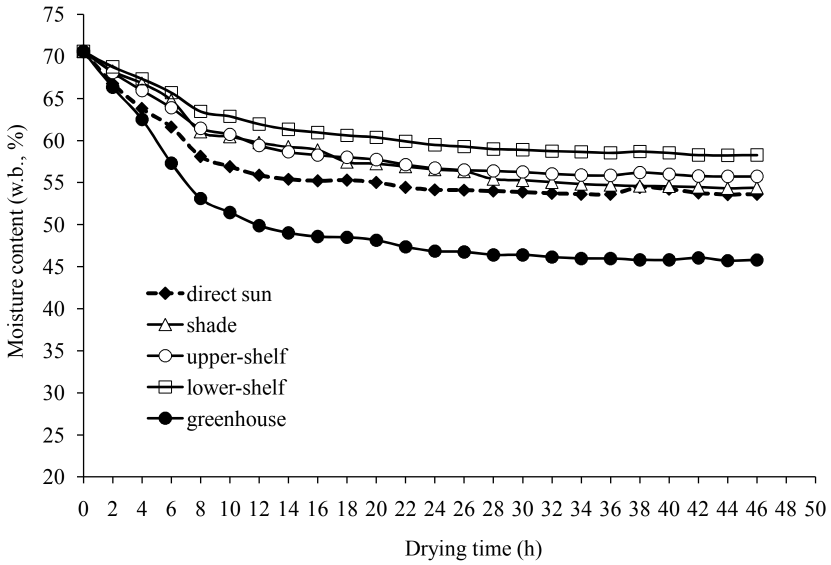

Fig. 8. Moisture content versus drying time for drying sage in March before flowering stage

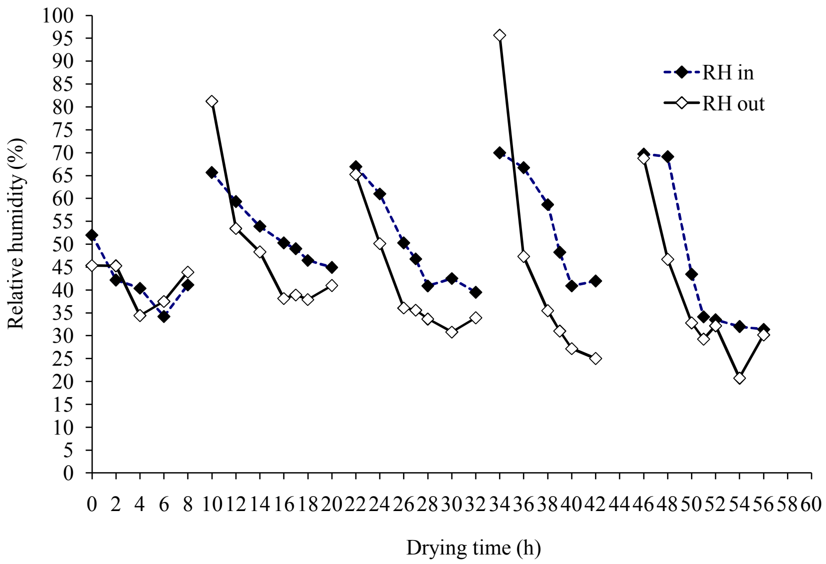

Fig. 9. Relative humidity (RH, %) versus drying time (h) in summer drying

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2010. Averages of the horizontal radiation during the investigation (begins from 2 h after the sunrise, for 10 h drying time in August and 8 h in March), temperature and relative humidity of ambient air and wind speed were addressed. Within the investigation period in March, active wind speed was noticed.

Sage moisture reduction

Sage moisture contents based on wet basis versus drying time is shown in Fig. 7 for August (summer) drying season; meanwhile, it is shown in Fig. 8 for drying in March. From the Figs 7 and 8 it is obvious that when sage was dried in the UPPSD, the lowest moisture content was obtained for sage drying in the upper shelf, compared to other locations of the dryer or with shade barn dryer. Rate of percentage reduction in the moisture content (determined as: %, w.b./h) for drying sage in August and March was considered. It was found that this value does not depend upon the prevailing weather conditions and the drying system in use only but also on the drying stage. For instance, the values found at the end of the 1st drying day (falling stage) were 1.219361%, 2.51277%, 1.850632%, and 1.405998%, w.b./h for average of shade dryer, upper shelf, lower shelf and dryer basement, respectively. However, the values of 0.062531%, 0.127459%, 0.141001%, and 0.09954%, w.b./h were obtained for the same drying processes at the 5th day (stable moisture content with the surrounding environment).

Meanwhile, low moisture removed was noticed when sage was dried before flowering stage in March compared with drying in summer season (August). Percentage moisture contents based on wet basis dried under the prevailing weather conditions of March after 10 drying days reached to 45.96%, 59.05%, 53.94%, 55.89%, and 58.32% for sage drying in the greenhouse dryer, under direct sun-rays, in the shade barn dryer, and in the upper and lower shelf of UPPSD, respectively. This might refer to an increase of the ambient air temperatures, intensity of the solar radiation and chimney height (4 m) for the summer run. It created an increase in the mass flow rate of the passive drying air in the unglazed transpired solar dryer for instant due to the pressure differences over March run.

Relative humidity and sage drying

Fig. 9 shows ambient and drying-air relative humidity for the UPPSD for five consequent drying days in summer. Generally, reduction of relative humidity for the drying air was noticed as well as for the drying air when the UPPSD and greenhouse dryers were used to dry sage in March (Fig. 10). It should be mentioned that relative humidity of the interior air of the greenhouse was near to that of the UPPSD especially within sage drying in March (Fig. 10).

Temperature of drying air and its effect on sage

For ambient air drying higher air temperature resulted in lower relative humidity and higher vapour pressure deficit and thus in higher mass transfer (moisture evaporation) rate. A typical relationship between ambient and UPPSD drying air temperature versus drying time is given in Fig. 11 for August run, while Fig. 12 represented it for March. Fig. 13 then represents temperature of greenhouse dryer and temperature of the penetrated sun-rays inside the greenhouse dryer.

Average ambient air temperature within the investigation periods was found as 31.5 ± 1°C for August and 27.2 ± 0.7°C for March. Meanwhile, dryer air temperatures were found as 39.2 ± 0.8°C and 36.8 ± 1.1°C for August and March, respectively. For the greenhouse dryer within March trial, the average interior air temperature was found as 31.8 ± 0.98°C. This means that the temperatures do not affect the volatile oil components of sage plants. According to Venskutonis (1997) who found that at 30°C total content of volatile compounds isolated by DE (Distillation Extraction) was insignificant.

From Figs 11 till 13, temperature increase above ambient level per the unit of incident solar radiation was determined

$$(T_d - T_a)/G \ (°\text{C m}^2/\text{W})$$

where:

T_d – drying air temperatures

T_a – ambient air temperatures

G – incident global radiation

It varied for drying in summer and March for UPPSD and greenhouse dryers, respectively. The values were found as 0.0209 ± 0.00177°C m^2/W for the summer run, compared to 0.0215 and 0.00769°C m^2/W in March for UPPSD and greenhouse dryer, respectively. The used solar radiation was that measured in different sides of the passive dryers.

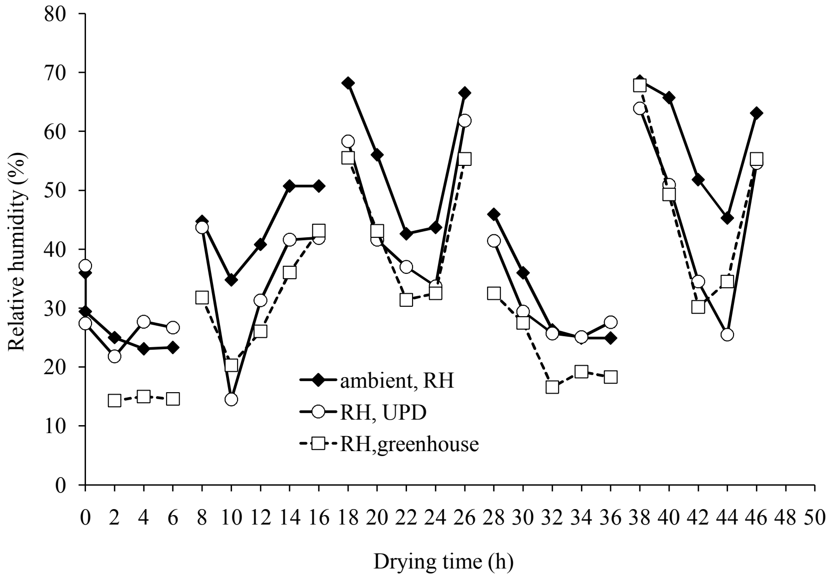

Fig. 10. Relative humidity (RH, %) versus drying time (h) in March drying; anbient; RH: relative humidity of ambient air; RH, UPD: Relative humidity inside the unglazed perforated solar dryer; RH, greenhouse: Relative humidity inside the greenhouse dryer.

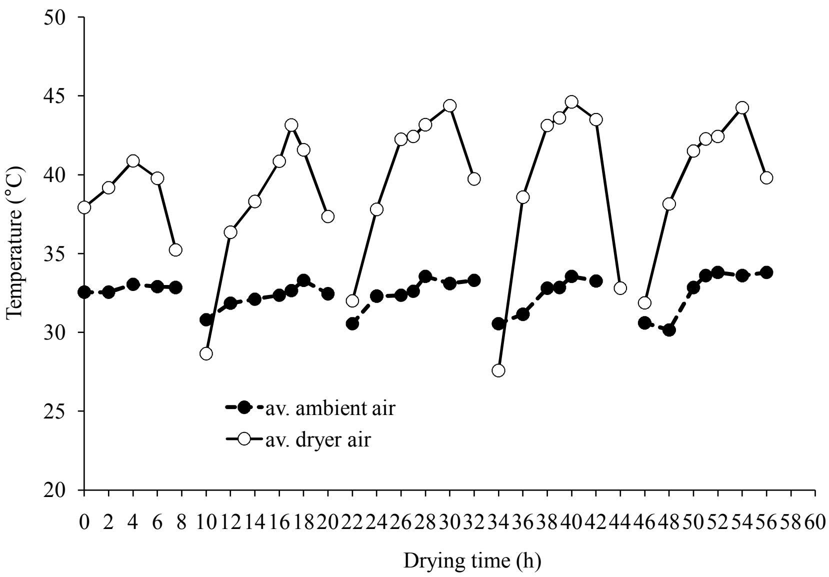

Fig. 11. Ambient and dryer air temperatures (August trial)

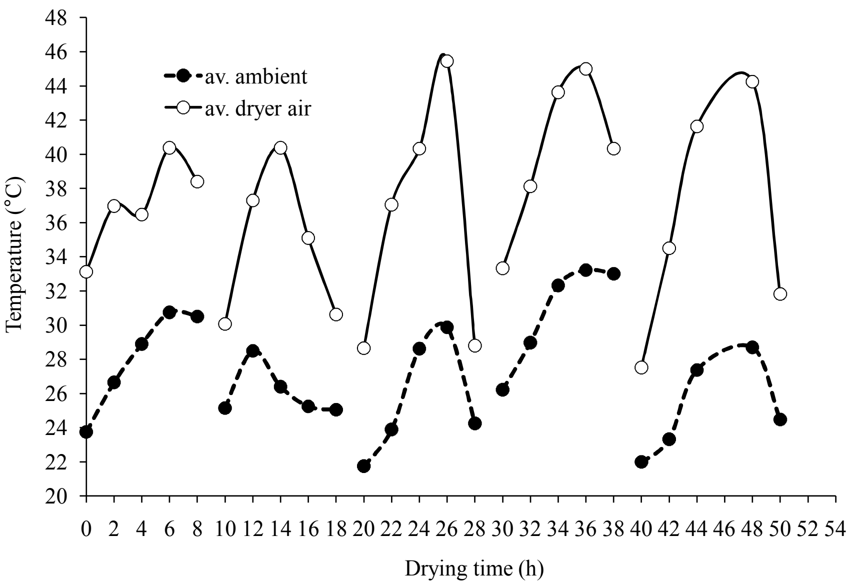

Fig. 12. Ambient and UPPSD dryer air temperatures (March trial)

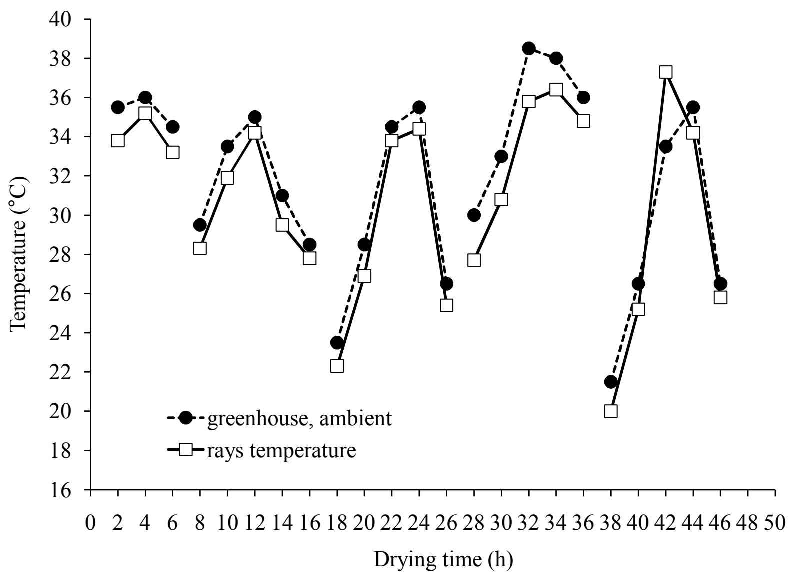

Fig. 13. Temperature of sun-rays and ambient temperature inside the greenhouse (March trial)

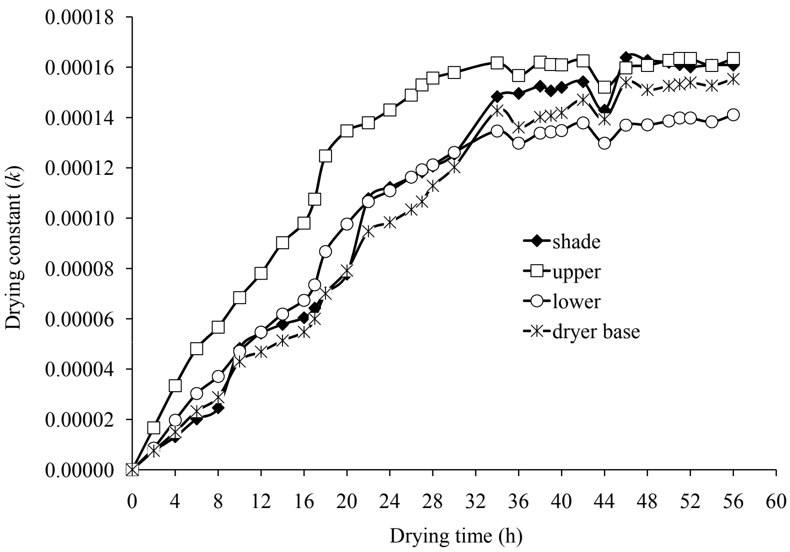

Fig. 14. Drying constant versus drying time (h) for different treatments (carried out in August 2009)

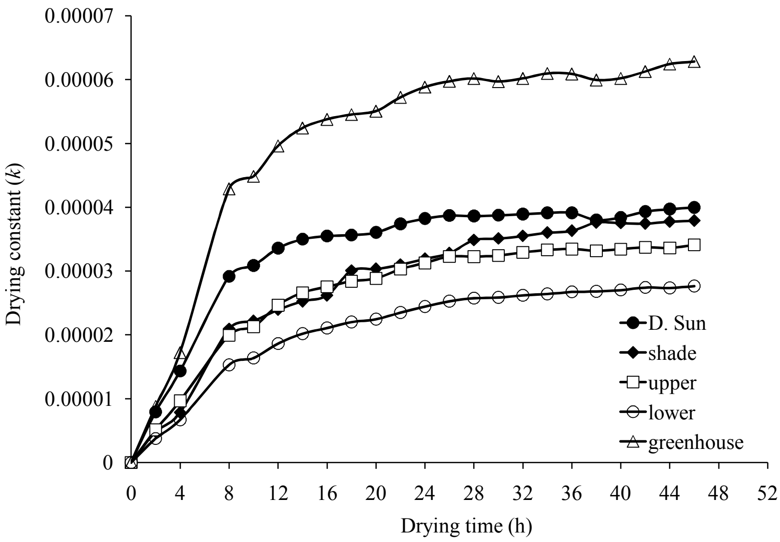

Fig. 15. Drying constant versus drying time (h) for different treatments (carried out in March 2010); D. Sun: Direct-sun rays sample

Table 3. Average sage drying constant (k) for different drying techniques

	UPPSD [Unglazed passive transpired (perforated) solar dryer]				
	shade	upper	lower	dryer base	av. UPPSD
In Aug;ust	0.000102 ± 0.000332	0.000121 ± 0.000354	9.67206×10^{-5} ± 0.000302642	9.63×10^{-5} ± 0.0003	0.000104778 ± 0.000264148

	direct sun	shade drying	upper shelf	lower shelf	av. UPPSD	greenhouse-dryer
In March	$3.31485 \times 10^{-5} \pm 2.24674 \times 10^{-6}$	$2.84 \times 10^{-5} \pm 2.29 \times 10^{-6}$	$2.69 \times 10^{-5} \pm 2.01 \times 10^{-6}$	$2.12 \times 10^{-5} \pm 1.65 \times 10^{-6}$	$2.40254 \times 10^{-5} \pm 1.83109 \times 10^{-6}$	$5.06 \times 10^{-5} \pm 3.67 \times 10^{-6}$

Sage drying constant

When the hygroscopic equilibrium moisture is reached, water exchanges between air and the water activity become identical to equilibrium moisture content increase.

Fig. 14 shows sage drying constant determined for the UPPSD drying method compared to the shade drying in summer; Fig. 15 shows comparison for other different methods in March run.

As shown in Fig. 14, the UPPSD reduces the relative temperature of drying air, enhancing the drying process. From the reduction of moisture content and also the drying constant, it is seen that the upper shelf was exceeding drying of sage, which refers to the chimney on the top of the shelf. The solar chimney enhances air to be sucked fast and resulting reduction in the moisture content, taking into consideration no plenum in the UPPSD, as it was investigated before in previous research. The sage drying constant in summer can be arranged according to the position of plants inside the UPPSD as: upper self, lower shelf, dryer basement. Drying in shade comes after the upper-shelf, while average drying constant for the three samples of the UPPSD was still higher than for drying sage in shade barn dryer, it was 0.000104778 ± 0.00026 compared to 0.000102 ± 0.00033 for shade dryer.

Table 3 averaged sage drying constant for different passive solar dryers (a) in August and (b) in March.

Microbial load

Results obtained from the microbial tests for different passive drying methods are given in Table 4. It shows total counts of fungi and bacteria before and after drying processes. The data give random variation for the total count. In some instances the results show higher counts after drying processes. The increase in total microbes number after drying may refer to different factors such as source, technique of agriculture (organic or not), anatomical and chemical structure of the plan or the inequity of exposing all dryers to wind dust (which import spores). The key factor of all of these is the number of toxicogenic fungi (fungi producing mycotoxins) and the amount of mycotoxins produced. More studies will be needed in the near future to evaluate the toxicogenic fungi and to determine the efficacy of the proposed designs.

Drying temperature discussed did not cause an appreciable reduction in microbial number; relatively low drying temperature had no effect on spore counts. Since the drying runs were not replicated, it is difficult to determine the effect of drying temperature on the microbial count for the dried samples.

The sage medicinal plants were dried without washing and it should be noted that total counts of microbial load for all treatments were less than in the fresh plants apart from that for UPPSD either

Table 4. Microbial load for different passive drying methods for each cm^2 of sage leaves

Treatment	Fungi count	Bacteria count	Total count
Fresh plant	10	15	25
Shade drying	6.5	14.5	21
Greenhouse dryer	8	13.5	21.5
Direct sun	16.5	3.5	20
Higher shelf	21.5	15	36.5
Lower shelf	13	15	28

in the upper or lower shelf. This might refer to the south–north orientation of the dryer; i.e. door of the dryer in the north side opened each two hours to weigh the dried samples, which let spores dry with the wind of north direction.

CONCLUSIONS

The study conducted to the following conclusions:

- Sage can be dried in different investigated passive solar dryers. Drying air temperature did not reach to the limit which affects the volatile oil even in the month of August, which enables using it with no fear of affecting the sage quality.
- Sage drying constant for March trial can be arranged in the descendent order as: drying in greenhouse solar dryer, drying sage under the direct sun-rays, drying in shade dryer barn (100% protection from sun-rays), drying sage in the unglazed perforated passive solar dryer UPPSD.
- In March sage drying constant in the UPPSD upper shelf was higher than lower shelf as well as in August.
- Average drying constant of sage in the UPPSD in August trial (upper shelf, lower, and dryer basement) was higher than shade drying.
- The upper shelves play a significant role in drying constant; the upper shelf had higher drying constant than lower shelf either in March or August.
- The effect of the drying methods on the microbial load represented as total count of bacteria and fungi for surface area per 1 cm^2 did not show the differences due to usage of different drying methods.

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